REMARKS

This is in response to the Office Action that was mailed on December 1, 2005. Previous amendments of claim 1 and 14 are partially reversed by the present Amendment. No new matter is introduced by this Amendment. Claims 1, 3-8, 10, 12, 14, and 16-18 are pending in the application.

Applicant respectfully requests reconsideration of the restriction requirement on the ground that the inventions of claims 17 and 18 are so closely related to the inventions of claims 1, 3-8, 10, 12, 14, and 16 that all of these claims could be conveniently examined together in the present application.

Claims 1, 3, 5-8, 10, 12, 14, and 16 were rejected under 35 U.S.C. §103(a) as being unpatentable over U.S. Patent No. 4,979,200 (hereinafter "Umemoto") and in view of Japanese patent publication JP 08-313699 A (hereinafter "Ohara"). The rejection is respectfully traversed, for reasons already of record in prior papers filed by Applicant in the present application.

Furthermore, however, Applicant now presents the 18 May 2006 Declaration under 37 CFR 1.132 of Hiroshi Ogawa. Mr. Ogawa's 18 May 2006 Declaration establishes that the radiation image conversion panel of the present invention - which is produced by thermo-compressing at least two sheets which have been separately coated and dried - provides

unexpectedly superior properties as compared to radiation image conversion panels made in a manner not contemplated by the present claims.

Three sets of two types of radiation image conversion panels were constructed, one set in accordance with the present invention and one set by a different method. In set "A", the upper-layer phosphor sheet had a thickness of 180 µm and the lower-layer phosphor sheet had a thickness of 100 µm. In set "B", the upper-layer phosphor sheet had a thickness of 140 µm and the lower-layer phosphor sheet had a thickness of 140 µm. In set "C", the upper-layer phosphor sheet had a thickness of 100 µm and the lower-layer phosphor sheet had a thickness of 180 µm.

As can be seen from the Declaration, the ***light emission*** quantity (%) for Examples "A", "B", and "C" of the invention was at least 100%, while the light emission quantity (%) for Comparative Examples "A", "B", and "C" was significantly less than 100%. In addition to this unexpected benefit of the present invention, further test results reported in the Declaration establish that the radiation image conversion panel Examples of the present invention had less graininess noise than did the radiation image conversion panels of the Comparative Examples.

Also, the radiation image conversion panel Examples of the present invention were characterized by significantly ***greater sharpness*** than were the radiation image conversion panels of the Comparative Examples. In the Declaration, sharpness was measured by modulation transfer

function (MTF). Applicant encloses a copy of "The Fundamentals of MTF, Wiener Spectra, and DQE" which was downloaded from http://aapm.org/meetings/99AM/pdf/2798-87374.pdf. "Measuring MTF (experimentally) - Digital Detectors (Pre-Sampled)" at the lower half of page 9 of this document describes an MTF measuring method similar to the method carried out in the experiments described in the enclosed Declaration.

For reasons already of record in prior papers filed by Applicant in the present application, and based upon the additional experimental evidence submitted herewith, Applicant is clearly entitled to a patent on the claims presently under consideration by the Examiner.

Should there be any outstanding matters that need to be resolved in the present application, the Examiner is respectfully requested to contact Richard Gallagher (Reg. No. 28,781) at (703) 205-8008.

Respectfully submitted,

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MSW/RG RG
1982-0149P

The Fundamentals of MTF, Wiener Spectra, and DQE

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Motivation

Goal of radiology: to diagnosis and treat disease by

Role of Medical Physicist: to help maximize patient benefit while minimizing the cost of the diagnostic imaging study

e.g. diagnostic information vs.. radiation dose

comparison of methods or systems

computed radiography vs. plain film

MRI vs. US

Motivation

Two steps in the radiologic process:

1. image production and display
   physical measures (MTF, NPS, NEQ, DQE)
2. image interpretation
   observer studies (ROC)

Physical Measures of Image Quality

What is a good (or valid) measure of
image quality?

image of a mammogram

series of images
(rose 1)

Perceived Image Quality is Proportional to SNR

$$SNR = C\sqrt{AQ}$$

where: SNR = signal-to-noise ratio
C = image contrast of the object
A = area of the object
Q = number of quanta per unit area

Outline of Talk

Image Quality Metrics
- what are they?
- what do they mean?
- how are they determined?

Rose Model

$$SNR = C\sqrt{AQ}$$

Assumptions: (ideal detector)
- no blurring
- no added noise
- perfect absorption of incident quanta

Why Work in the Spatial Frequency Domain

performance of a detector depends on the object being imaged

a single analysis in the spatial frequency domain can be used to predict performance of all possible objects

all real objects can be decomposed into sine waves of different amplitudes, frequencies, and phases

computation in spatial frequency domain is easier than in the spatial domain

(multiplication vs. convolution)

Spatial Resolution

can be characterized by limiting resolution

measured using bar pattern

a more complete description is given by modulation transfer function (MTF)

image

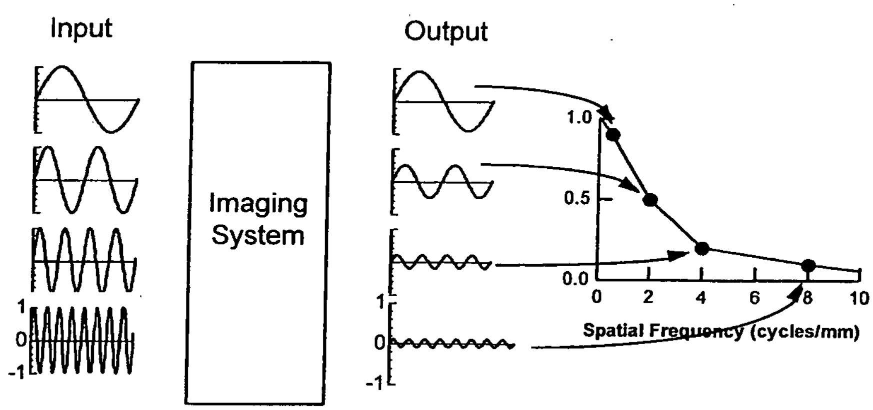
rossmann beads and needles

need MTF for intermediate freq; limiting resolution is for high freq only

Outline of Talk

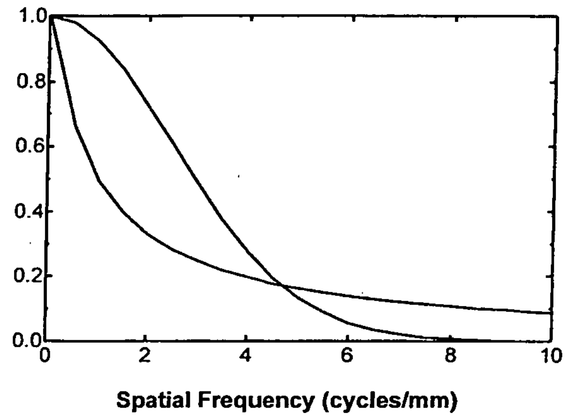
Image Quality Metrics
- what are they?
- what do they mean?
- how are they determined?

Measuring MTF (conceptually)



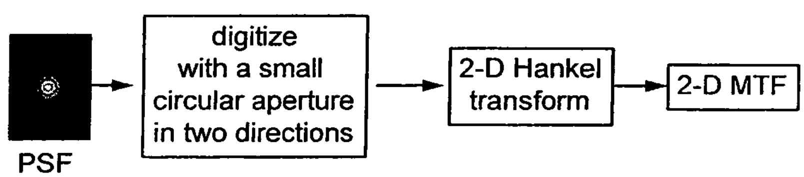
measures change in the <u>amplitude</u> of sine waves

MTF Curves

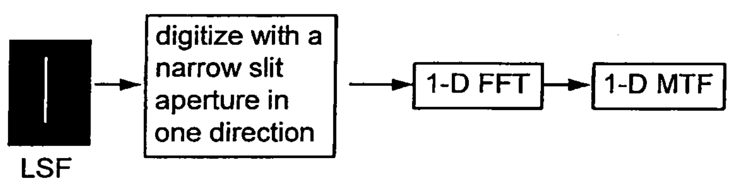


Measuring MTF (theoretically)

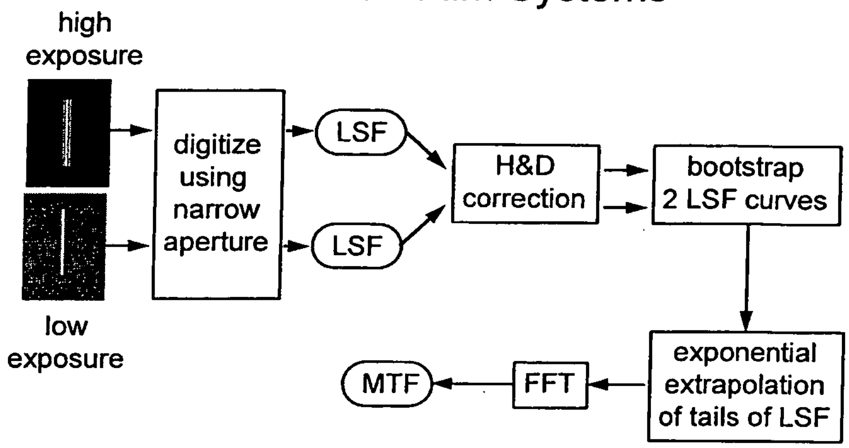
a POINT is composed of all spatial frequencies



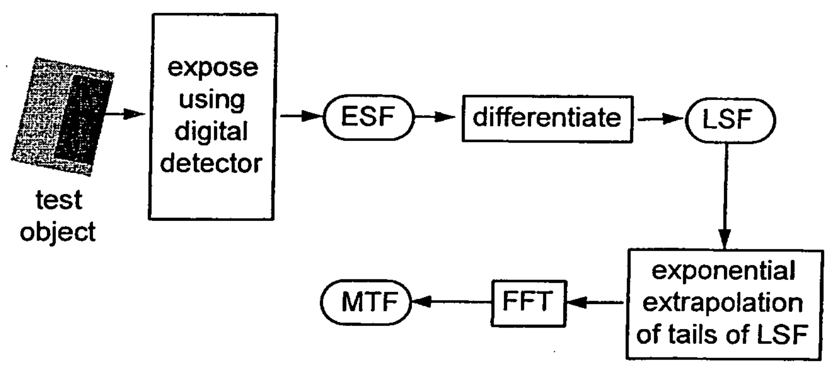
a LINE is composed of all spatial frequencies in one direction and zero frequency in the other



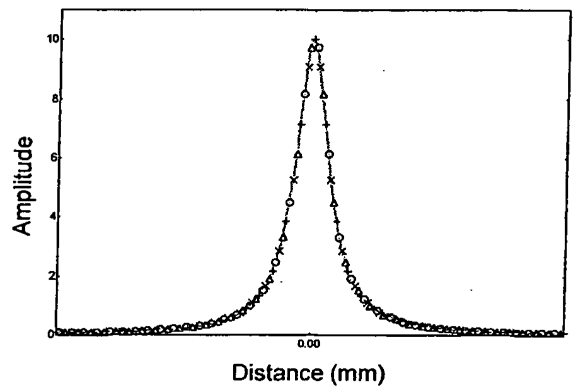
Measuring MTF (experimentally)
Screen-Film Systems



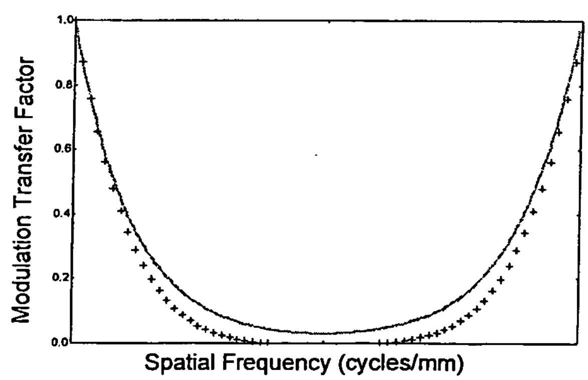
Measuring MTF (experimentally)
Digital Detectors (Pre-Sampled)



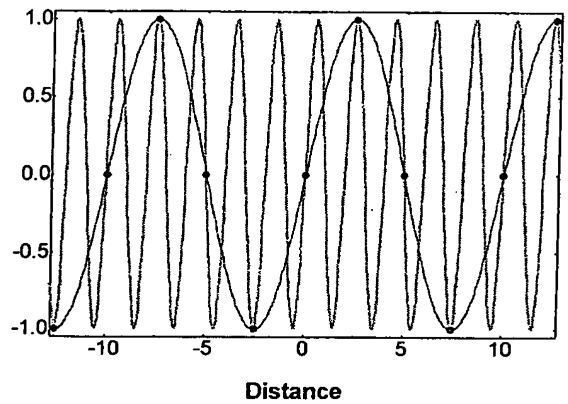
Oversampling the LSF



Aliasing



Aliasing



MTF of Digital Detectors

non-isotropic --> 2-D display is necessary
MTF in orthogonal directions can be different

Noise

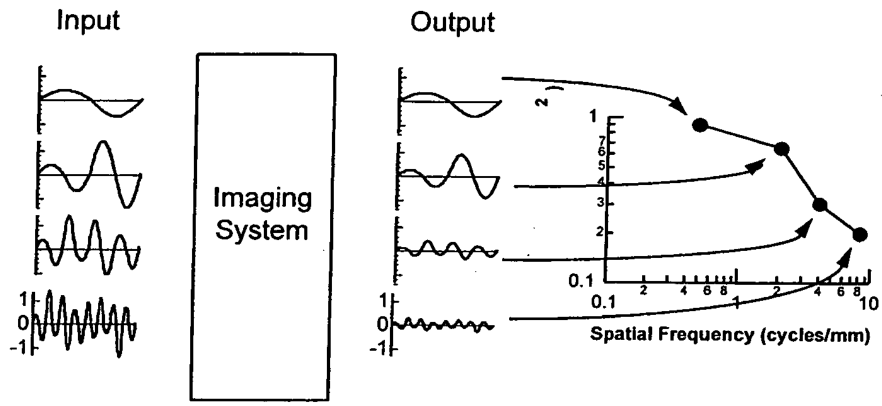
noise can be characterized by standard deviation in the output image

a more complete description is given by the noise power spectrum

noise image

same standard deviation, but different texture

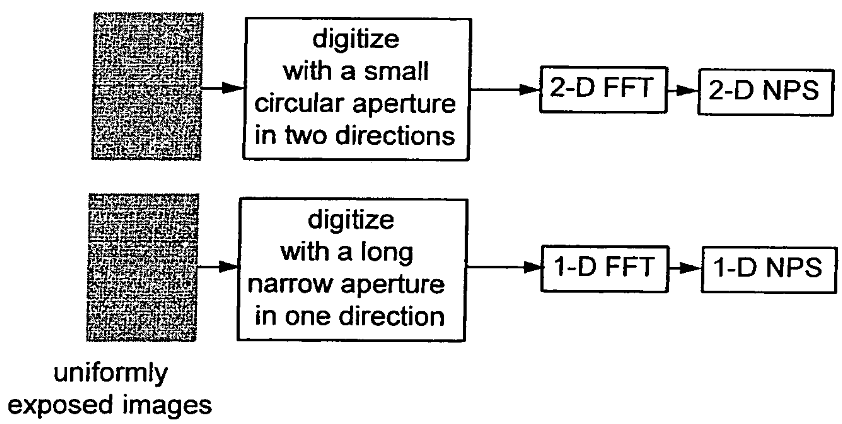
Measuring NPS (conceptually)



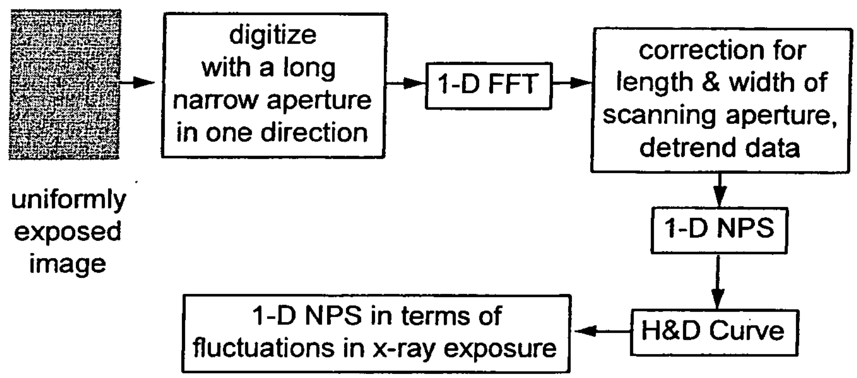
Measure change in the
variation in the amplitude of sine waves

Measuring NPS (theoretically)

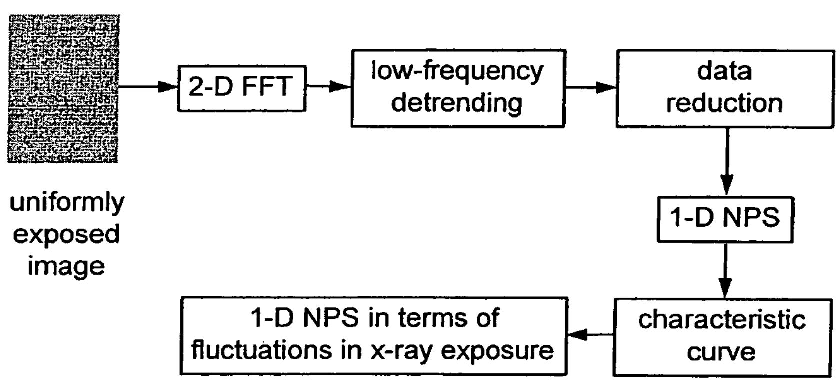
a uniform x-ray exposure contains noise at all spatial frequencies



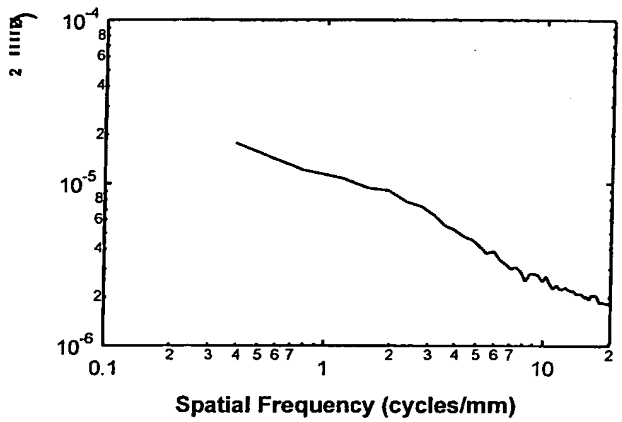
Measuring NPS (experimentally)



Measuring NPS (experimentally) Digital Detector



Typical NPS



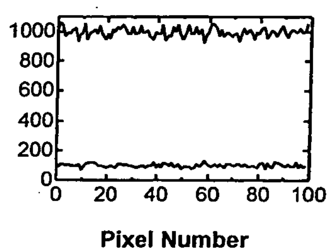
Alternate Methods for Measuring Noise Power Spectra

Fourier Transform of autocovariance function

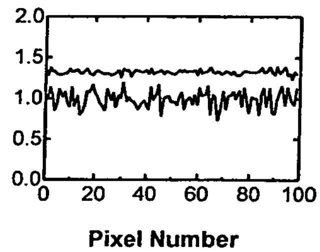
analog method

Paradox

Linear Conversion
(Digital Detector)



Logarithmic Conversion
(Screen-Film System)



noise increases with exposure

- noise decreases with exposure

Solution

Digital Detector

$I = kQ$

$dI = kdQ$

noise α $\overline{Q}$

Screen-Film Systems

$D = G \log(Q) + D_o$

$dD = G\, d\log(Q)$

$= G \log_{10}e\, d\ln Q$

$= G \log_{10}e\, dQ/Q$

noise α $(Q)^{-0.5}$

assuming Poisson noise, $dQ = \sqrt{Q}$

Signal-to-Noise Ratio

Photon Counting

$$\text{signal} = \Delta Q$$
$$= k\Delta Q$$
$$\text{SNR} = \Delta Q\,(Q)^{-0.5}$$
$$= C\,(Q)^{0.5}$$

Screen-Film Systems

$$\text{signal} = \Delta D$$
$$= G\,\Delta[\log(Q)]$$
$$= G\,\log_{10}e\,\Delta Q/Q$$
$$\text{SNR} = \Delta Q/Q\,(Q)^{0.5}$$
$$= C\,(Q)^{0.5}$$

where $C = \Delta Q/Q$, the radiation contrast of the object

Signal-to-Noise Ratio

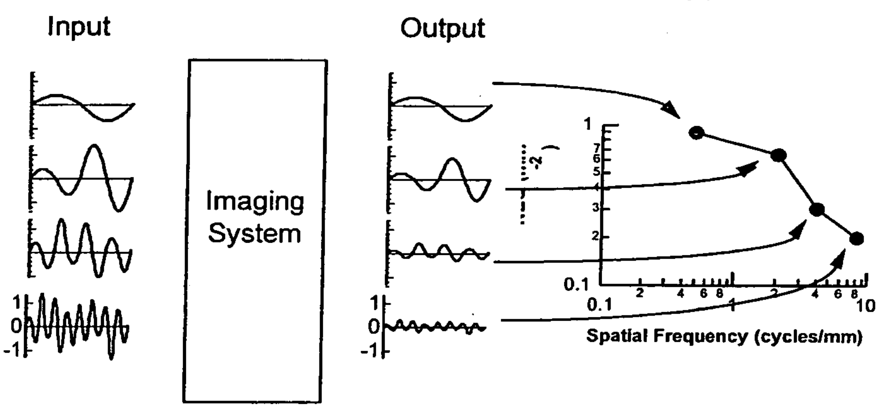
can be characterized

a more complete description is given by NEQ (noise equivalent quanta)

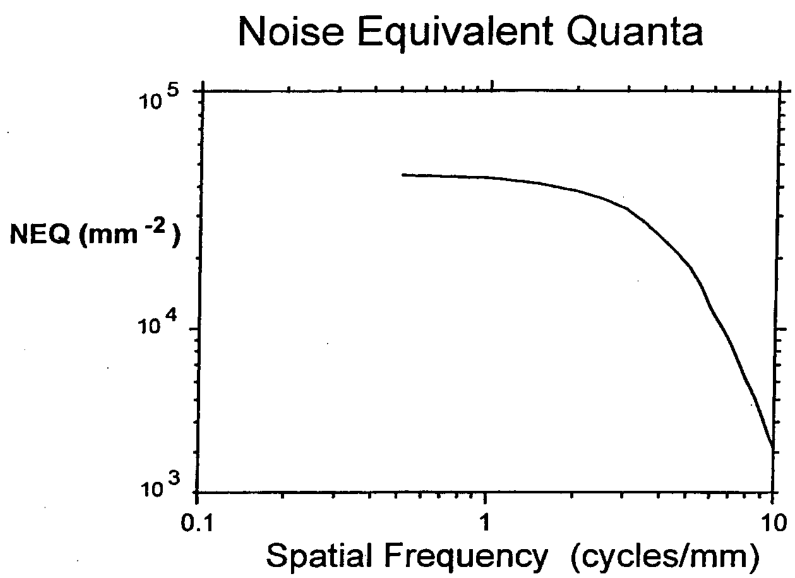
image

CD phantom of digital system
 digital low MTF low noise
 film high MTF High noise
 digital better

Measuring NEQ (conceptually)



Measure change in the <u>mean amplitude</u> and in the <u>variation in the amplitude</u> of sine waves



Noise Equivalent Quanta (NEQ)

Definition:

$$NEQ(\omega) = Q\ DQE(\omega)$$

Q = # of quanta incident on the detector per unit area
(assumes unit contrast)

Detective Quantum Efficiency (DQE)

Definition:

$$DQE(\omega) \quad \frac{\overline{\Delta Q^2(\omega)}}{\overline{\Delta O^2(\omega)}} \left(\frac{dO}{dQ}\right)^2$$

where ω = spatial frequency

$\overline{\Delta O^2}$ = mean-squared variation in the output

$\overline{\Delta Q^2}$ = mean-squared variation in the input

$\frac{dO}{dQ}$ = gain of system

Interpretation of DQE

$$DQE(\omega) = \frac{SNR^2_{out}(\omega)}{SNR^2_{in}(\omega)}$$

$SNR_{out}(\omega)$ = SNR in the output image

$SNR_{in}(\omega)$ = SNR incident on the detector

characterizes the efficiency of information transfer from the input to the output of the system

allows comparison to an ideal system

ranges from 0 to 1.0

Interpretation of NEQ

$$NEQ(\omega) = Q\ DQE(\omega)$$

For a noise-limited system, $SNR_{in}^2 = Q$

$$NEQ(\omega) = SNR_{in}^2(\omega)$$

is the number of quanta that an ideal detector would have needed to yield the same SNR

absolute measure of image quality

ranges from 0 to infinity

assumes unit contrast

How to Calculate DQE (general)

$$DQE(\omega) = \frac{Q\ MTF^2(\omega)}{W(\omega)} \left(\frac{dO}{dQ}\right)^2$$

where $MTF(\omega)$ = MTF of detector

$W(\omega)$ = noise power spectrum of image

$\frac{dO}{dQ}$ = gain of the system

How to Calculate DQE
(screen-film system)

$$\gamma \quad \frac{dD}{d(\log_{10}Q)} = \frac{Q}{\log_{10}e}\frac{dD}{dQ}$$

$$\frac{dD}{dQ} = \frac{\gamma \log_{10}e}{Q}$$

$$DQE(u) = \frac{\gamma^2 (\log_{10}e)^2\, MTF^2(u)}{Q\,W(u)}$$

u = one dimensional spatial frequency

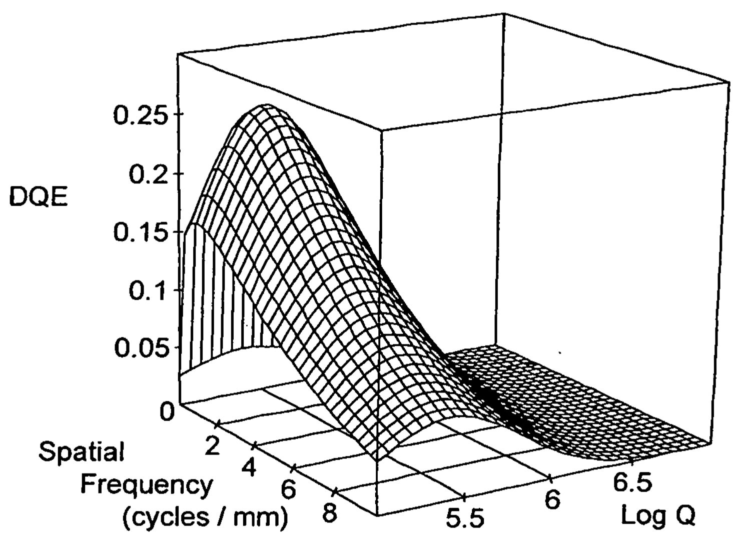
Exposure Dependence

screen-film systems are non-linear

NEQ and DQE are functions of both spatial frequency and x-ray exposure

$$NEQ(\omega, Q) = \frac{\gamma(Q)^2 (\log_{10}e)^2 MTF^2(\omega)}{W(\omega, Q)}$$

H&D curve



DQE
0.25
0.2
0.15
0.1
0.05
0
Spatial Frequency (cycles / mm)
2
4
6
8
5.5
6
6.5
Log Q

Things to Remember

DQE comparisons assume equal SNR_{in}

may not be true: x-ray exposure, kVp

$SNR_{in} = C \quad \overline{Q}$

DQE analysis assumes shift-invariant system

DQE & NEQ are measures of SNR

if image is not noise limited, but contrast limited, a system with higher NEQ may not produce a better image

information

Relationship Between SNR and NEQ

$$SNR = \left[\int |S(\vec{\omega})|^2 NEQ(\vec{\omega})\, d\vec{\omega} \right]^{1/2}$$

where $S(\vec{\omega})$ is the spatial frequency spectrum of the object

Summary

NEQ and DQE are useful parameters for characterizing and understanding medical imaging systems

NEQ and DQE can serve as a basis for comparing different imaging conditions and modalities

NEQ may be useful in furthering our understanding of image perception

Recommended Reading

(1) ICRU Report 41: Modulation transfer function of screen-film systems.

(2) BRH Report: MTF's and Wiener spectra of radiographic screen-film systems.

(3) J. C. Dainty, R. Shaw: Image Science (Academic Press, London, 1974), Chap. 6, 7, and 8.

(4) J. S. Bendat, A. G. Piersol: Random Data: Analysis and Measurement Procedures 2nd edition, (Wiley, New York, 1986).

(5) A Rose, Vision: Human and Electronic (Plenum, New York, 1973).

(6) C. E. Metz and K. Doi: Transfer function analysis of radiographic imaging systems. Phys Med Biol **24**: 1079 (1979)

(7) R. A. Sones, G. T. Barnes: A method to measure the MTF of digital x-ray systems. Med Phys **11**: 166 (1984).

(8) H. Fujita, K. Doi, M. L. Giger: Investigation of basic imaging properties in digital radiography. 6. MTFs of II-TV digital imaging systems. Med Phys **12**: 713 (1985).

(9) I. A. Cunningham, A. Fenster: A method for modulation transfer function determination from edge profiles with correction for finite-element differentiation. Med Phys **14**: 533 (1987).

(10) M. Dragnova, J. A. Rowlands: Measurement of the spatial Wiener spectrum of nonstorage imaging devices. Med Phys **15**: 151 (1988).

(11) J. A. Rowlands, G. DeCrescenzo: Wiener noise power spectra of radiological television systems using a digital oscilloscope. Med Phys **17**: 58 (1990).

(12) I. A. Cunningham and B. K. Reid: Signal and noise in modulation transfer function determinations using the slit, wire, and edge techniques, Med Phys **19(4)**:1037-1044, 1992.

(13) J.M. Sandrik, R.F. Wagner, Absolute measures of physical image quality: Measurement & application to radiographic magnification, Med. Phys. **9**: 540(1982).

(14) R.M. Nishikawa, M.J. Yaffe, Signal-to-noise properties of mammographic film-screen systems, Med. Phys. **12**, 32-39 (1985).

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(17) J. T. Dobbins, D.L. Ergun, L. Rutz, *et al.*, DQE(f) of four generations of computed radiography acquisition devices, Med Phys **22**, 1581-1593 (1995).

(18) M. L. Giger and K. Doi, Investigation of basic imaging properties of digital radiography. Part 1: modulation transfer function, Med Phys **11**, 287-295 (1984).

(19) M. L. Giger, K. Doi and C. E. Metz, Investigation of basic imaging properties of digital radiography. Part 2: noise Wiener spectrum, Med Phys **11**, 797-805 (1984).

(20) C. E. Metz, R. F. Wagner, K. Doi, D. Brown, R. M. Nishikawa and K. Myers, Toward consensus on quantitative assessment of medical imaging systems, Med. Phys. **22**, 1057-1061 (1995).